Pharmaceutical compositions containing the long pentraxin PTX3

The present invention relates to pharmaceutical compositions containing the long pentraxin PTX3 (PTX3) or one of its functional derivatives. In particular, the invention relates to the aforesaid compositions for the therapy of infectious and inflammatory diseases or tumours.

The invention also relates to expression vectors containing the complete cDNA sequence coding for PTX3 or one of its functional derivatives, recombinant host cells transfected with such expression vectors and a method for producing PTX3 or one of its functional derivatives. Further, the invention relates to gene therapy methods for the treatment of tumours, based on the use of the aforesaid expression vectors.

To date, we have yet to fully understand the biological function of PTX3, a protein which is expressed in various types of cells, most notably in mononuclear phagocytes and endothelial cells, after exposure to the inflammatory cytokines Interleukin 1beta (IL-1beta) and Tumour Necrosis Factor alpha (TNF-alpha).

To date, there has also been no description of any therapeutic use of PTX3 or of its functional derivatives.

PTX3 consists of two structural domains, an N-terminal unrelated to any known molecule, and a C-terminal similar to the short pentraxins such as C-reactive protein (CRP). A substantial degree of similarity has been found between human PTX3 (hPTX3) and animal PTX3s.

The PTX3 gene is located on chromosome 3 of the mouse in a region similar to the human 3q region (q24-28), in agreement with the documented location of hPTX3 in the 3q 25 region. Furthermore, mouse PTX3 (mPTX3) (Introna M., Vidal Alles V., Castellano M., Picardi G., De Gioia L., Bottazzi B., Peri G., Breviario F., Salmona M., De Gregorio L., Dragani T.A., Srinivasan N., Blundell T.L., Hamilton T.A. and Mantovani A.: Cloning of mouse PTX3, a new member of the pentraxin gene family expressed at extrahepatic sites. Blood 87 (1996) 1862-1872) is very similar to hPTX3 in terms of organisation, location and sequence (Breviario F., d'Aniello E.M., Golay J., Peri G., Bottazzi B., Bairoch A., Saccone S., Marzella R., Predazzi V., Rocchi M., Della Valle G., Dejana E., Mantovani A., Introna M.: Interleukin-1-inducible genes in endothelial cells. Cloning of a new gene related to C-reactive protein and serum amyloid P component. J. Biol. Chem. 267:22190, 1992).

In particular, the degree of identity between the sequences is 82% between the human and mouse gene and reaches 90% if conservative substitutions are considered.

The high degree of similarity between the hPTX3 and mPTX3 sequences is a sign of the high degree of conservation of pentraxin during evolution (Pepys M.B., Baltz M.L.: Acute phase proteins with special reference to C-reactive protein and related proteins (pentraxins) and serum amyloid A protein. Adv. Immunol. 34:141, 1983).

CRP is a marker for immuno-inflammatory and infectious disease. After a trauma, a lesion or infection of a tissue triggers off, in the affected subject, a complex series of reactions aimed at preventing extension of the damage, at destroying the infecting organism and at activating the repair process in order to restore normal function. This process constitutes the so-called acute-phase response, and the main marker currently used for the acute-phase response is CRP. In normal human serum, in fact, it is present in concentrations of less than 10 μg/ml, but can increase more than 1,000-fold in response to a trauma or inflammation (Koj A.: "Acute phase reactants" in "Structure and Function of Plasma Proteins". Allison A., ed. Plenum Press, New York, 1974, pp. 73-131).

Previous therapeutic uses of CRP are already known. For instance, US Patent 4,857,314 dated 15.08.1989 discloses the use of CRP in combination with TNF for the treatment of tumours.

International patent application PCT/US94/02181 dated 24.02.1994 discloses mutants of CRP which are useful for the preparation of diagnostic kits for determining immunocomplexes in

biological fluids and for the treatment of viral and microbial diseases, tumours and endotoxic shock.

International patent application PCT/US94/09729 dated 26.08.1994 also discloses mutants of CRP which are useful for the preparation of diagnostic kits and for the treatment of viral and microbial diseases and tumours.

The ability of PTX3 to recognise and bind specifically to ligands which are also recognised by short pentraxins has been evaluated *in vitro* using purified recombinant PTX3. Short pentraxins such as CRP and SAP (serum amyloid P component) are characterised by their ability to recognise and bind in a calcium-dependent manner to a broad spectrum of ligands, including phosphocholine, phosphoethanolamine, many sugars, the best characterised of which is an agarose derivative rich in pyruvate [methyl 4-6-O-(1-carboxyethylidene)-beta-D-galacto-pyranoside] or MOβDG, complement fragments and proteins of the extracellular matrix, particularly fibronectin and type IV collagen. Unlike the short pentraxins, PTX3 is unable to bind either calcium (assessed by Inductive Coupled Plasma/Atomic Emission Spectroscopy) or phosphocholine, phosphoethanolamine or MOβDG. Moreover, PTX3 is unable to bind extracellular matrix proteins such as fibronectin or type IV collagen. On the other hand, PTX3 is capable of binding the C1q complement fragment which is also recognised by the short pentraxins (Table 1). It

should be stressed, however, that, whereas CRP and SAP have to be cross-linked to bind C1q, PTX3 is capable of recognising and binding this complement fragment in the naturally occurring form.

Surprisingly, it has now been found that the long pentraxin PTX3 or its functional derivatives are useful therapeutic agents, particularly for the therapy of infectious and inflammatory diseases or tumours.

What is meant by "long pentraxin PTX3" is any long pentraxin PTX3, i.e. regardless of its natural (human or animal) or synthetic origin. Human long pentraxin PTX3 (see sequence 1 and Fig. 5) is the preferred form.

A convenient method of producing substantial amounts of long pentraxin PTX3 or one of its functional derivatives consists in preparing expression vectors (e.g. plasmids) containing the complete cDNA sequence coding for PTX3 or one of its functional derivatives and in using these to transfer eukaryotic cells in culture (e.g. Chinese hamster ovary cells, CHO). After cloning the recombinant host cells thus transfected, the cell clone capable of producing the highest levels of PTX3 is selected.

According to the present invention, the above-mentioned expression vectors containing the cDNA sequence coding for long pentraxin PTX3 are also utilised in gene therapy methods for the treatment of tumour conditions.

A first gene therapy method consists in:

a) taking samples of cells from a patient suffering from a tumour;

b) transfecting these cells with an expression vector containing the complete cDNA sequence coding for long pentraxin PTX3 or one of its functional derivatives; and

c) inoculating the tumour patient with these transfected cells.

A second gene therapy method for the treatment of tumours consists in:

a) preparing an expression vector of viral origin (such as an adenovirus or retrovirus) containing the complete cDNA sequence coding for long pentraxin PTX3 or one of its functional derivatives; and

b) injecting the tumour affected patient with the expression vector thus obtained.

Though the mechanism of action of PTX3 or its functional derivatives has yet to be definitively clarified, their anticancer activity in any event is not attributable to a direct cytolytic or cytostatic effect on the tumour cells, but rather to mechanisms mediated by the host and related to the leukocyte recruitment ability exerted by these compounds, as will be described below.

There now follows a description of the experimental procedures and results are reported demonstrating the unexpected activity of the compounds according to the invention described herein.

Production of recombinant PTX3: a fragment containing the complete cDNA sequence of human PTX3 (sequence 2 and Fig. 6) was subcloned in the Bam H1 site of the expression vector pSG5 (Fig. 1) (Stratagene, La Jolla, CA, USA) and transfected in CHO cells using the precipitated calcium procedure. A clone selected in G418, capable of producing large amounts of PTX3, was used as a source from which the protein was purified by chromatography by means of ion exchange and gel filtration.

Binding of PTX3 to C1q: the binding of PTX3 to C1q was assessed in an ELISA system. A 96-well plate was covered with 250-500 ng of C1q per well (one night at 4°C) and then washed with PBS with Ca^{++} and Mg^{++} containing 0.05% Tween 20 (PBS). The wells were then blocked with 5% milk in PBS (2 h at room temperature) and subsequently incubated with variable concentrations of PTX3 (30 min at 37°C). After a further series of washings, the plate was incubated with a rat monoclonal antibody to PTX3 (1 h at room temperature) and then with the second antibody, a peroxidase-conjugated rat anti-IgG antibody (1 h at room temperature). After washing, chromogen was added and absorbance was read at 405 nm using an automatic plate

reader. In a number of experiments, the wells were covered with PTX3 and C1q binding was evaluated using an anti-C1q antibody.

Biotinylated protein was used to determine the C1q binding affinity. PTX3 was biotinylated according to standard procedures using an activated biotin modified by the addition of a "spacer arm". (SPA – Società Prodotti Antibiotici).

Figures 2(A) and 2(B) give the C1q binding and binding affinity results. These results show the very substantial degree of C1q binding and binding affinity of PTX3.

Leukocyte recruitment: the leukocyte recruitment induced by PTX3 was studied *in vivo* in the subcutaneous pocket system. The subcutaneous pocket was induced in the experimental animal by means of two subcutaneous injections of 5 mL of air into the animal's back with an intervening interval of three days. On day 6, 1 μg of PTX3 in 0.5% carboxymethylcellulose was administered into the pocket. After 4 h, the animals were anaesthetised and the pocket was washed with 1 mL of saline solution. The washing liquid was recovered and was submitted to a total count and a differential count of the cells present.

The results obtained are reported in Figure 3 and show the substantial leukocyte recruitment capacity of PTX3 in normal animals, whereas Figure 4 shows the results obtained in genetically modified

animals, without C1q, in which the leukocyte recruitment is significantly lower.

Anticancer activity: a line of murine mastocytoma P815 was co-transfected by electroporation with the expression vector pSG5 containing the cDNA of human PTX3 or its antisense and the vector pSV2 which endows the transfected cells with neomycin resistance. After selection with neomycin 0.5 mg/mL, the cells were cloned by limit dilution.

To assess the production of PTX3, $2.5x10^5$ cells were cultivated in 200 µL of RPMI + 3% FCS for 24 h and the supernatant was tested by ELISA. The clones obtained produced protein levels ranging from 1 to 35 ng/mL, while the clones containing the antisense produced no measurable levels of PTX3. The clones considered showed the same growth rate *in vivo*.

Male DBA/2N CrlBR mice aged 8-10 weeks were subcutaneously injected with $1x10^5$ cells of P815 PTX3-producing clones or with clones containing the antisense gene. The mice were monitored 3 times daily for occurrence of tumours and once daily for survival.

The results obtained are reported in Table 2 and show the efficacy of PTX3, in this experimental model of gene therapy, in bringing about healing of the animals and complete rejection of the tumour after the take of the inoculated tumour cells.

These results are statistically significant with $p<0.01$ (Fisher test) both as compared to controls and to the group treated with the antisense.

In the light of these results it is clear that the anticancer activity reported above correlates closely with the leukocyte recruitment which occurs in the mouse as a result of recognition of the C1q by PTX3. In genetically modified mice, no such leukocyte recruitment occurs. The leukocyte recruitment capacity, on the basis of the anticancer activity of the compounds according to the invention, indicates that these compounds may also have a useful application in the treatment of diseases caused by pathogens such as bacteria, fungi, protozoa or viruses.

TABLE 1 PENTRAXIN BINDING ABILITY TO VARIOUS LIGANDS

	CRP	SAP	PTX3
Ca^{2+}	+	+	-
Phosphocholine	+	-	-
Phosphoethanolamine	+	+	-
MOβDG	-	+	-
C1q	+	+	+
Type IV collagen	ND	+	-
Fibronectin	ND	+	-

ND: test not performed

TABLE 2 *IN VIVO* ANTICANCER ACTIVITY OF PTX3

Clone[1]	Reject[2]
Parent P815 (control)	4/25
P815-AS1 (antisense)	3/8
P815-PTX3-1 (sense)	14/14*

1 : 1 x 10^5 cells of the clone indicated were injected subcutaneously.

2 : Number of animals that definitely reject the tumour out of total number of animals in which it took.

* : $p<0.01$ as compared both to mice treated with parent cells and to mice treated with cells of the antisense clones (Fisher test).

Brief description of drawings

Figure 2: PTX3 binding to C1q. Panel A shows the binding of the supernatant of the culture containing PTX3 (sense) and of the purified protein to C1q and C1s immobilised on plate. The binding is assessed as optical density (O.D.) at 405 nm. Panel B shows the saturation curve obtained with the biotinylated protein. The kinetic parameters were calculated using the non-linear fitting statistical method.

Figure 3: PTX3-induced leukocyte recruitment: 1 μg of FTX3 is injected into a subcutaneous pocket induced in the back of CD 1 mice by inoculation of 5 ml of air.

Figure 4: PTX3-induced leukocyte recruitment in normal animals and in genetically modified animals without, C1q. PTX3 is injected into a subcutaneous induced on the back of the animals.

Sequence SEQ. ID. NO 1: Amino acid sequence of human FITX3. The underlined amino acids constitute the peptide signal. Mature hPTX3 consists of 364 amino acids.

Sequence SEQ. ID. NO 2: Nucleotide sequence of fragment of cDNA of human PTX3. Upper case letters denote nucleotides coding for the protein, while lower case letters denote regions at 3' and 5'not translated but present in the construct.